NOTES

ON

CERTAIN EXPLOSIVE AGENTS.

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PREFACE.

In March, 1875, the writer prepared a paper which was published in pamphlet form by the Bureau of Ordnance, Navy Department, under the title of "Notes on Explosives and their Applications in Torpedo Warfare." This paper was intended for the use of the naval service, and especially for instruction at the Torpedo Station, and was mainly derived from the notes of a course of lectures on Explosives, delivered at the Torpedo Station in 1874.

Since the publication of this pamphlet, much interest has been expressed in it by persons outside the service, and numerous inquiries have been made concerning it. Commodore Jeffers, Chief of the Bureau of Ordnance, having kindly consented to its reprinting, it is offered in its present shape to those interested in the subject.

In preparing it for the press at this time, there has been omitted a discussion of the applications of explosives to torpedoes, which was included in the earlier pamphlet; and in its place will be found some observations of a general character upon the use of some explosives for blasting purposes. Some other alterations and additions have been made.

No attempt is made in these pages at an extended treatment of the subject of Explosives. It is intended only to briefly examine a few of the most important topics included under it, from a practical point of view.

At the present time, the detonating explosives (nitro-glycerine and gun-cotton) have become prominent, and are largely used, while they are yet unfamiliar to many persons. Especial attention will, consequently, be paid to them, after a short discussion of the general principles governing all explosive action.

Considerable space is devoted to details of some operations in use at the Torpedo Station. They have not been described before, and may possess some points of interest.

Those who may wish to study the subject of explosive agents minutely can consult books on chemical technology and a few special works; but to a large extent its literature is to be found in scientific and technical periodicals, and in occasional publications of various kinds.

W. N. H.

UNITED STATES TORPEDO STATION,
    Newport, R. I., June 1, 1875.

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NOTES ON CERTAIN EXPLOSIVE AGENTS.

CHAPTER I.

EXPLOSIONS AND EXPLOSIVE BODIES.

EXPLOSIVE REACTIONS.

ALL chemical changes, whether of combination or decomposition, are called reactions.

Reactions take place in or between molecules. The same atoms are found after a reaction as were present before, but differently arranged or united, forming molecules different from those which entered into the reaction. The reaction, then, is a change in the manner in which the attractions or affinities of the atoms are exerted. The operations of these attractions are governed by the circumstances under which they are exercised. Then, in order to produce any desired result, certain necessary conditions must be fulfilled.

These conditions vary between extreme limits. Thus, in one compound, the attractions which bind together its parts may be so feebly exercised that the slightest change in its surrounding circumstances will bring about its decomposition, while to reverse those of another compound may require that the most powerful agencies should be exerted for a long time. Again, compounds which are stable at the ordinary temperature may be broken up when moderately heated, or reactions which occur at the ordinary pressure may be entirely altered if the same materials are brought together at a different pressure.

Reactions may go on rapidly or slowly, and be accompa-

nied by evolution of gas, of heat, light, electricity, &c. When these accompaniments are of a certain kind, explosive effect results, and we have *explosive* reactions; but such chemical changes are governed by the same laws as all reactions.

DEFINITION OF EXPLOSION.

The term explosion is rather loosely used. Considering it as synonymous with explosive reaction, it may be defined as a chemical action, causing the sudden or extremely rapid formation of a very great volume of highly expanded gas.

EXPLOSIVE EFFECT.

Explosive effect is caused by the blow or impulse given by this rapid production of gas in a confined space.

The explosive character of the change, then, depends —

1st, Upon the great change of state produced; that is, the formation of gas very much greater in volume than the substance from which it is derived, and which is still more expanded by the heat evolved.

2d, Upon the shortness of the time required for the change to take place.

Both these causes operate to a greater or less extent in all explosive reactions. When both are fully exerted, the most energetic chemical reaction, or in other words, the most violent explosion, takes place. Also, the differences in explosions and explosive bodies depend upon the differing manner and proportions in which they are exerted. Thus, nitro-glycerine is much more powerful and violent than gunpowder, because it generates a larger volume of gas in a shorter time. Again, fulminating mercury is not more powerful than gunpowder, although the decomposition goes on more quickly, since the quantity of gas given off, and the temperature of the reaction, are less.

The kinds and quantity of gas given off in an explosive reaction depend upon the chemical composition of the explosive body and the character of the decomposition.

The heat evolved during the reaction adds to the effect by increasing the tension (expanding the volume) of the gas

formed. The heat given off in a reaction is an absolute quantity, the same whether the reaction goes on slowly or rapidly. But the *explosive* effect will evidently greatly depend upon the *rapidity* of the formation and expansion of the gas. Thus, if an explosive undergoes the same chemical change under all circumstances of firing, then the total amount of force developed will always be the same, but the *explosive effect* will be increased as the time of action is lessened.

CIRCUMSTANCES OF EXPLOSION.

Explosions are greatly affected by the circumstances attending them. Different substances, of course, give different results, from their different compositions and reactions. But we also find that the same substance will exercise a different explosive effect when fired under certain conditions than under others. These may affect either the rapidity or the results of the chemical change. By shortening the time of the reaction, the explosion is rendered sharper and more violent. With some explosives, the decomposition is different under different circumstances. Thus, gunpowder, when fired under great pressure, as in a mortar, gives different products than when fired unconfined.

Circumstances of explosion may be generally considered under —

1st, Physical or mechanical condition of the explosive body itself.

2d, External conditions.

3d, Mode of firing.

1st, *Physical or Mechanical Condition of the Explosive Body.*

Many instances may be given indicating the influence of its state upon the explosion of a substance. Thus, nitro-glycerine at temperatures above 40° Fah. is a liquid, and in the liquid condition may be violently exploded by a fuse or exploder containing fifteen grains of fulminating mercury. Below 40° it freezes and cannot be so fired.

The advantage of dynamite over liquid nitro-glycerine lies altogether in the fact that the former contains the explosive

body in another mechanical condition, more convenient and safer to use than the liquid form. The nitro-glycerine itself is the same chemically in either case.

The same mixture of charcoal, sulphur, and saltpetre gives a very different effect if made up into large grains than if made up into small ones.

Gun-cotton presents the most marked example of the effect of mechanical state, since it can be prepared in so many ways. If flame is applied to loose, uncompressed gun-cotton, it will flash off; if the gun-cotton is spun into threads or woven into webs, its rate of combustion may be so much reduced that it can be used in gunnery or for a quick fuse; powerfully compressed and wet, it burns slowly; dry gun-cotton may be exploded by a fulminate exploder; wet gun-cotton requires an initial explosion of a small amount of the dry, etc.

2d, *External Conditions.*

Confinement is necessary to obtain the full effect of all explosives. The most rapid explosion requires a certain time for its accomplishment. As the time required is less, the amount of confinement necessary is less. Then with the sudden or violent explosives, the confinement required may be so small that its consideration may be practically neglected. For instance, large stones or blocks of iron may be broken by the explosion of nitro-glycerine upon their surfaces in the open air. Here the atmosphere itself acts as a confining agent. The explosion of the nitro-glycerine is so sudden that the air is not at once moved.

Again, chloride of nitrogen is one of the most sudden and violent of all explosives. In its preparation it is precipitated from a watery liquid, and therefore is, when used, wet or covered with a very thin film of water. This thin film of water, not more than $\frac{1}{1000}$ of an inch in thickness, is a necessary and sufficient confinement; and, if it is removed, the explosive effect is much diminished.*

Gunpowder, on the other hand, requires strong confine-

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* Abel, Trans. Roy. Soc., 1869, 489.

ment, since its explosion is comparatively slow. Thus, in firing a large charge of gunpowder under water, unless the case is strong enough to retain the gases until the action has become general, it will be broken, and a large amount of the powder thrown out unburned. This is often the case in firing large-grained powder in heavy guns. The ball leaves the gun before all the powder has burned, and grains or lumps of it are thrown out uninjured.

The confinement needed by the slower explosives may be diminished by igniting the charge at many points, so that less time is required for complete explosion.

3d, *Mode of Firing.*

In any explosive reaction, the mode of bringing about the change exercises an important influence. The application of heat, directly or indirectly, is the principal means of causing an explosion. Thus, in gunnery, the flame from the percussion-cap or primer directly ignites the charge ; so also a fine platinum wire heated by an electric current will ignite explosive material, which is in contact with it. Friction, percussion, concussion, produce the same effect indirectly, by the conversion of mechanical energy into heat, which is communicated to the body to be exploded.

When one explosive body is used as a means of firing another, it may be considered that the blow delivered by the gas suddenly formed from the firing charge acts percussively upon the mass to be exploded. The particles of this gas are thrown out with great velocity, but, meeting with the resistance of the mass around them, they are checked, and their energy is converted into heat. It is found, however, that the action of explosives on one another cannot be perfectly explained in this way. If the action were simply the conversion of energy into heat, then the most powerful explosive would be the best agent for causing explosion. But this is not the case. Nitro-glycerine is much more powerful than fulminating mercury ; but fifteen grains of the latter will explode gun-cotton, while seventy times as much nitro-glycerine will not do it.

Chloride of nitrogen is much more violent than fulminating mercury, but larger quantities of the former than of the latter must be used to cause other explosions.

Again, nitro-glycerine is fired with certainty by a small amount of fulminating mercury, while with a much larger amount of gunpowder the explosion is less certain and feebler.

In these cases, it is evident that the fulminating mercury must have some special advantage, since it produces the desired effect more easily than the others. It may be considered that the fulminating mercury sets up a form of motion or vibration, to which the other bodies are sensitive. Just as a vibrating body will induce corresponding vibrations in others, so the peculiar rate of motion or wave of impulse, sent out by fulminating mercury, exerts a greater disturbing influence upon the molecules of certain bodies than that derived from the other substances.*

An explosive molecule is unstable, and very susceptible to external influences. Its atoms are in a nicely balanced equilibrium, which is, however, more readily overturned by one kind of blow than another. The explosive molecule takes up the wave of impulse of the fulminate, but the strain is too great, and its own balance is destroyed. So a glass may stand a strong blow, while a particular note or vibration will break it.

In the case mentioned above, of gun-cotton affected by nitro-glycerine or fulminate, the explosion of the nitro-glycerine is strong enough to tear and scatter the gun-cotton, but the blow, though very powerful, is not one that the gun-cotton is sensitive to ; on the other hand, the fulminate blow, though weaker, readily upsets the gun-cotton molecule.

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* Champion and Pellet have experimented (Comptes Rendus, LXXV., 110, 712) on the " Vibratory Motions produced by Detonants," and have found that the vibrations excited by different explosions are very different. Thus with a series of sensitive flames corresponding to the scale of g major, 0.03 grm. of iodide of nitrogen at five metres distance had no effect, while the same amount of fulminating mercury affected the flames a, c, e, f, g. At a less distance the iodide of nitrogen influenced the higher notes only, while the fulminate acted on all of them. Nitro-glycerine gave only negative results, due perhaps to the small range of the apparatus.

In addition, the explosion proceeds very differently when brought about in this way than when caused by simple inflammation. When a mass of explosive is ignited by a flame, the action extends gradually through it; but if it is exploded by a blow, acting in the manner above described, it is plain that the explosion will be nearly instantaneous throughout, since the impulse will be transmitted through the mass with far greater rapidity than an inflammation proceeding from particle to particle. The explosive reaction will then proceed much more rapidly, and the explosive effect will be much sharper, that is, more violent.

It is found that this difference in explosive effect according to mode of firing is very marked, and it is indicated in the use of the term Detonation.

DETONATION.

Detonation is the instantaneous explosion of the whole mass of a body. Thus, when gunpowder is fired in the usual manner, true combustion takes place, which goes on with comparative slowness from the surfaces of the grains toward their interiors. On the other hand, when nitro-glycerine is fired by means of fulminating mercury, the whole mass explodes simultaneously, or nearly so.

Doubtless, a certain time is always necessary; but with the so-called detonating explosives it can be practically neglected, and the explosion called instantaneous.

BODIES SUSCEPTIBLE OF DETONATION.

Some explosives seem to always detonate, no matter how fired (e. g. chloride of nitrogen, the fulminates, etc.), while others are detonated or not, according to the mode of firing (gun-cotton, gunpowder, etc.).*

Probably all explosives can be detonated if the right methods of doing so are known.

Gun-cotton seems to have a greater range of susceptibility to different modes of firing than any other explosive agent.

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* See page 7.

It can be made to burn slowly without explosion, and the rapidity of its action can be increased up to the detonating point. Nitro-glycerine always explodes powerfully, but its effect is much lessened when fired with gunpowder.

Gunpowder, as ordinarily used, is, of course, not detonated, as the violent, sudden effects of detonation would be undesirable. For other purposes (*e. g.* torpedoes, blasting, etc.) it would be a great advantage if it could be made to give more violent explosive effects by a peculiar mode of firing. It has been demonstrated that this can be done, although the best mode of doing it, or whether detonation is actually accomplished, is not known.* Experiment in this direction can hardly fail to give valuable results.†

Probably a mechanical mixture, like gunpowder, can never be brought by any mode of firing to approach as near to a perfect detonation as the chemical substance nitro-glycerine or gun-cotton; but, even if not detonated, better effects for certain uses may be obtained from it if the proper means is used.

Roux and Sarrau have recently published some interesting results of experiments on the different explosive effects produced by some bodies by certain modes of firing.‡ They divide explosions into two kinds: detonations or explosions of the first order, and simple explosions or explosions of the second

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* The following experiment, devised by Abel, and which the writer has often repeated, illustrates very well the different behavior of gunpowder with the detonating mode of firing: Three small iron cylinders (inch steam pipe, 4–5 inches long, with a cap screwed on one end, answers very well) open at the top, are bedded in the earth with their mouths level with the surface. In one is placed a charge of fine-grained gunpowder, which is fired with an electric fuse primed with mealed powder. The powder explodes with a dull report, leaving the cylinder in place and uninjured. The second is filled with sand, and contains an electric fulminate fuse. On firing this, the cylinder is bulged and cracked a little, but not moved. The third contains the same amount of powder as was put in the first, but is fired with a fulminate fuse similar to that in the second. In this case the report is sharp, the cylinder is torn to pieces, which are scattered about, and the earth in which it is imbedded is thrown out so as to leave a considerable cavity.

† Some experiments of this kind have been already made at the Torpedo Station, and they are now being carried on.

‡ Comptes Rendus, Oct. 5, 1874.

order. Simple explosions are produced either by direct in-
flammation or by a small charge of gunpowder. Detonations
are obtained from nitro-glycerine, gun-cotton, picric acid, and
certain picrates, by exploding with fulminating mercury.

Fulminating mercury, they state, does not detonate gun-
powder; but if the exploding charge is a small amount of
nitro-glycerine, itself detonated by fulminate, then an explo-
sion of the first order is obtained from gunpowder. The rela-
tive effects were approximately measured by determining the
quantities necessary to rupture small cast-iron shells of nearly
equal strength.

The following are among the results given, showing the
great difference in force of the two kinds of explosion: —

	Explosive Force.	
	2d order.	1st order.
Gunpowder	1.00	4.34
Gun-cotton	3.00	6.46
Nitro-glycerine	4.80	10.13

MODES OF PRODUCING DETONATION.

Detonation is produced by the application of the requisite
concussive force by means of a detonating fuse or exploder.
A detonating fuse is one which causes explosion by the blow
or shock it gives, while the ordinary fuse ignites by simple
inflammation. Detonating fuses are generally charged with
fulminating mercury, a substance which seems to be specially
adapted for this use. With such fuses are fired nitro-glycerine
and its preparations and dry gun-cotton. Compound detonat-
ing fuses are sometimes employed, such as the " primer," for
wet gun-cotton, which is a small charge of the dry gun-cotton,
fired by fulminate, and the nitro-glycerine fuses of Roux and
Sarrau, mentioned above.

There seems to be for each explosive about a certain amount
and kind of force required to effect detonation, which must
not be materially departed from.

If the exploder is too weak, inflammation or a feeble explo-
sion only will result; if too heavily charged, it is more likely
to scatter or disintegrate the material acted upon than to
explode it.

There is also a relation between the mass of the explosive and the charge of the detonator which must be observed. This relation is more marked with some explosives than with others. Thus, nitro-glycerine is a body easily detonated, and the same amount of fulminate seems to fire equally well all usual quantities. If a single particle is detonated, the action quickly extends through the whole mass.

Other substances, less easily detonated, require that as the mass is increased the force applied shall be increased, so that all the particles shall receive a sufficient blow, otherwise only a part will be detonated.

COMPARATIVE VALUE OF DETONATION.

In a detonation we have the fullest *explosive* effect. The suddenness of the explosion concentrates the blow, making it sharp and violent. For certain purposes this is much more effective than would be the same total amount of force more slowly exerted. For instance, in blasting hard rock, the violent explosion will throw out and shatter much more rock proportionally than the slower explosion, which tends to escape in the direction of the least resistance. Therefore, in blasting with nitro-glycerine, for example, hard tamping is unnecessary. The explosion is too sudden to allow the gases to blow out the tamping and so escape. The effect is consequently equal in all directions. The advantages gained in blasting with nitro-glycerine and its preparations are so great that their use is constantly increasing, in spite of their high cost and the prejudice against them on account of the many accidents that have occurred with them.

In submarine work, such as torpedo firing or removing obstructions, the advantage of the violent explosion is very great. The slower explosion tends to raise or heave up a large volume of water, spreading and weakening the effect; whereas the detonation is more concentrated, tearing its way through the water. Therefore, unless actual contact of the charge with the object can be obtained, it is advantageous to use a detonating explosive; since its action, although perhaps more local, is much less weakened by the layer of water through which it passes.

In general, when a scattering, tearing effect is desired, the detonating explosive must be used.

RELATIVE FORCE OF EXPLOSIVE BODIES.

The experimental determination of the actual force exerted by explosive bodies is very difficult, particularly with those that detonate. As Sprengel remarks,* " It is to be regretted that no exact method exists for comparing the force of detonating explosives."

However, a comparison may be based upon theoretical ideas that has some value. Berthelot † calculates the quantity of heat generated in the explosive reaction and the volume of gas formed. The product of these numbers gives a " term of comparison between the pressures." The following table shows the results so obtained : —

EXPLOSIVE SUBSTANCE.	Quantity of Heat evolved per kilo.	Volume of Gas formed.	Product of two preceding Numbers.
	cal.	m. c.	
Sporting Powder	641,000	0.216	139,000
War Powder	608,000	0.225	137,000
Blasting Powder	510,000	0.173	88,000
Powder with Excess of Saltpetre	673,000	0.111	75,000
Nitrate of Soda Powder	764,000	0.248	190,000
Chlorate of Potash Powder	972,000	0.318	309,000
Chloride of Nitrogen	316,000	0.370	117,000
Nitro-glycerine	1,320,000	0.710	939,000
Gun-cotton	590,000	0.801	472,000
Nitrated Gun-cotton	989,000	0.484	480,000
Chlorated Gun-cotton	1,420,000	0.484	680,000
Picric Acid	687,000	0.780	536,000
„ „ and Saltpetre	923,000	0.408	376,000
„ „ and Chlorate of Potash	1,424,000	0.408	582,000
Picrate of Lead	126,000	0.120	150,000
„ of Copper	407,000	0.270	109,000
„ of Silver	262,000	0.116	29,000
„ of Mercury	190,000	0.212	40,000
„ of Potash	578,000	0.585	337,000
„ of Potash and Saltpetre	852,000	0.337	286,000
„ of Potash and Chlorate of Potash	1,422,000	0.337	478,000

* Journal Chemical Society, XI. 802.
† Sur la Force de la Poudre et les Matieres Explosives, 1872.

Taking the numbers given in the last column, we can make a comparison that "accords in general with experience." (Berthelot.)

Sarrau [*] considers that the force of an explosive substance is nearly proportional to the product of its heat of combustion by the weight of the permanent gas produced by the combustion. From experimental determinations of the weights of permanent gas given off on explosion, he calculates the force of some explosive substances, and thence derives the following table, showing the relative force they exert. In this table, the force exhibited by powder is taken as unity, and is the mean of determinations made with five varieties.

NAME OF SUBSTANCE.	Relative Force.
Saltpetre Powder	1
Chloride of Nitrogen	1.08
Nitro-glycerine	4.55
Gun-cotton	3.06
Picrate of Potash	1.98
Mixture of 55 parts Picrate of Potash and 45 parts Saltpetre .	1.49
Mixture of equal weights of Picrate and Chlorate of Potash .	1.82

Theoretical comparisons of force do not, however, indicate accurately relative effects as found in practice. If the character of the chemical change that occurs in an explosion is perfectly known, then the total amount of force exerted may be calculated, but the manner in which this force is exercised is of great importance in determining the actual effect obtainable.

This brings up again (see page 8) the second of the conditions of explosive character in a reaction; viz., the time required for the change. Thus, the explosive force of one body is so rapidly exercised that it may be entirely utilized, while another acts so slowly that considerable force is lost or not used in certain circumstances of practice.

If perfect detonation was accomplished in every instance,

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[*] Recherches Théoriques sur les Effets de la Poudre et des Substances Explosives, 1874.

then the actual force exhibited would approach very nearly the theoretical proportions. But, as explosive bodies differ in their manner of action, comparisons of force will vary according to the mode of comparison employed.

For example, supposing Sarrau's table to be theoretically correct, it will at once be noticed that according to it nitro-glycerine and gun-cotton do not exceed gunpowder in as great a degree as they do practically. This is because, under the circumstances in which these bodies are used, the force they exert is more completely utilized than can be that of powder under the same circumstances. Again, there may be conditions in which powder will be proportionally more effective than the quicker burning explosives.

In the same table, chloride of nitrogen is given as having but a trifle more force than gunpowder; yet the explosion of chloride of nitrogen is so sudden and violent that destructive effects may be produced with it far surpassing any thing that can be accomplished with powder under the same circumstances.

Therefore, whatever may be the relative force *possessed* by the different explosive substances, we must depend for a knowledge of their *comparative value* upon the results of practice; and it will be found that relative values will vary very much with the conditions of use.

COMPOSITION OF EXPLOSIVE BODIES.

An explosive body must be composed of constituents which will, on explosion, form large quantities of permanent gas, and they must be so associated that the reaction can be readily brought about, and will proceed with great energy and rapidity. With few exceptions, explosives are essentially composed of carbon, oxygen, and nitrogen. On explosion, the carbon and oxygen unite to form carbonic acid gas, and nitrogen is set free in the gaseous state. Carbon and oxygen readily combine, and the combination is attended with a great evolution of heat. The nitrogen plays an important part. In the explosive, it is in combination with oxygen; but its attraction for the latter is comparatively feeble, and it

readily gives up its oxygen to the carbon, assuming itself the gaseous state. The nitrogen, then, is a means of closely associating together the particles of carbon and oxygen before direct combination takes place, and also increases the quantity of gas formed.

In an ordinary combustion, the oxygen of the air slowly comes into contact with the combustible ; but in an explosive, the oxygen and carbon are already very near, so that extensive action follows the exciting cause.

Besides these three elements, others are frequently present which act in the same manner, or are necessities of constitution. Thus, in gunpowder, besides carbon there is sulphur, another combustible body, and the nitrogen and oxygen are introduced in the form of saltpetre (potassium nitrate), which contains potassium. In many explosives, hydrogen enters with the carbon, and plays a similar part.

It is convenient to divide explosive agents into explosive compounds and explosive mixtures.

In an explosive compound, the elements composing it are in chemical combination, and cannot be separated except by chemical change.

In an explosive mixture, the ingredients are mechanically mixed, and can be separated by mechanical means.

In an explosive mixture, properly so called, the separate constituents do not have explosive properties, but these belong to the mixture only. For instance, gunpowder is an explosive mixture, since sulphur, charcoal, and saltpetre have separately no explosive properties. These appear when the three substances are put together, and therefore belong only to the mixture. On the other hand, dynamite is not an explosive mixture according to the above definition of that term, since it is made up of an explosive compound, nitro-glycerine, and an inert body which has no explosive properties by itself or with other substances.

The nitro-glycerine is mixed with the inert absorbent ; but the explosive character is due to the nitro-glycerine only, and is not dependent upon the fact of mixture.

While this distinction is a good one in the main, it is not

always strictly applicable. There are some mixtures which contain substances having themselves explosive properties. In such a case, however, the explosive properties of the compound are not sufficiently great to render it useful by itself, and it enters into the mixture as a combustible ingredient. Thus, a picrate has a certain quantity of oxygen available in the explosive reaction, but not enough; so it is mixed with a substance supplying oxygen, such as potassium nitrate (saltpetre) or potassium chlorate.

The number of explosive mixtures that have been made is very large, and the number that may be made is almost endless. They are all, however, essentially alike in composition, each containing a combustible substance, and one capable of furnishing oxygen. Some general considerations in regard to them will be presented without detail.

Of the great number of compounds known to possess explosive properties, nitro-glycerine, gun-cotton, the picrates, and the fulminates are the only ones that will be taken up. Nitroglycerine and gun-cotton are in extensive use as blasting agents, and are, therefore, the most important practically.

The first three are good examples of the constitution of an explosive. Each is formed from a body composed of carbon, hydrogen, and oxygen, by introducing into it a number of atoms of nitrogen and oxygen in feeble combination in place of part of the original hydrogen. In this way, a new substance is obtained, unstable from its greater complexity, and also from the peculiar condition of the added atoms. The nitrogen holds the oxygen but feebly, so that a slight disturbance of the equilibrium brings into action the stronger attractions of the carbon and hydrogen for oxygen.

The fulminates are probably similarly constituted, although their mode of formation is not so well understood.

Chloride of nitrogen and iodide of nitrogen have been mentioned in the foregoing pages. They are sensitive substances, exploding with slight provocation, the former with extreme violence. Their properties have been studied; and they have been occasionally employed for purposes of experiment, but only in very small quantities.

CHAPTER II.

NITRO–GLYCERINE.*

FORMATION.

NITRO-GLYCERINE is formed by the action of nitric acid upon glycerine at a low temperature. The process of manufacture consists essentially in the slow mixing of the glycerine with the acid, a low temperature being preserved during the whole operation, and in separating and washing the nitro-glycerine from the excess of acid with water.

Materials. The glycerine is the commercial article of good quality. It must be free from the adulterations often found in it.†

The nitric acid must be strong, having a specific gravity of not less than 1.45, and ought to be 1.48. Nitric acid of this strength cannot be obtained in the market, and must therefore be specially prepared for the purpose. This is done by careful distillation from sodium nitrate (Chili saltpetre) and sulphuric acid (oil of vitriol).‡

Before it is used the nitric acid is mixed with twice its weight of strong sulphuric acid (oil of vitriol). The sulphuric acid does not take a direct part in the production of the nitro-glycerine, but takes up the water which is formed during the reaction, thereby preventing the dilution of the nitric acid.

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* Nitro-glycerine has been made and used by the writer, at the Torpedo Station, for five years; and the statements in the text are derived from experience with it under many and varied conditions.

† The commonest impurity is fatty acid, due to imperfect decomposition of the fat. This is indicated by a precipitate when a solution of a lime salt is added to some of the glycerine mixed with water. A frequent adulteration is dextrin, or British gum.

‡ Another and perhaps a better method is to distil from a mixture of ordinary commercial nitric acid and sulphuric acid in glass retorts. Stronger nitric acid can be thus made, but with more trouble and expense. A still for this purpose has been mounted at the Torpedo Station, but has not yet been much used.

The sulphuric and nitric acids mixed in the proper proportions (one of nitric to two of sulphuric) are placed in a large stone-ware receiver, from which the mixture can be drawn as it is required.

The method used at the Torpedo Station is that of George M. Mowbray, with improved apparatus. The operation may be conveniently divided into two parts : —

1st, The conversion of glycerine into nitro-glycerine.

2d, The separation and washing of the nitro-glycerine.

Conversion of Glycerine into Nitro-glycerine.

The apparatus used for this purpose at the Station is shown on Plate 1. An elevation, section, and plan are given, the lettering being the same in the three.

A, A, A, A, A, A, are wooden troughs placed around the brick chimney D, D. In these troughs are the earthen-ware pitchers, *a, a, a, a, . . a*, which contain the acid mixture. On the shelf B, above the pitchers, are the bottles, *b, b, b, . . b*, which contain the glycerine. The bottles are loosely closed by wooden stoppers with broad rounded tops. Through holes in these stoppers pass loosely the rubber tubes, *c, c, c, c,* which reach to the bottom of the bottles, and carry small glass jets at their outer ends. Conical wooden plugs, *e, e, e, e,* are placed in the holes through the stoppers alongside the rubber tubes.

The steam-pipe G passes along the shelves B, B, just behind the glycerine bottles.

The air-main F passes under the shelf B, and carries on its under side a number of small short pipes or jets (two for each pitcher), to which are attached the rubber tubes, *d, d, d, d,* which hang over the pitchers.

In these rubber tubes are inserted glass tubes, long enough to extend to the bottom of the acid pitchers. In the elevation these tubes are out of the pitchers, but in the section they are in place, as if in use.

The troughs are made tight to hold the ice-water with which

the pitchers are surrounded. Partitions, with openings at the bottoms, cut off the corners of the troughs forming the clear spaces, f, f, f, f. These spaces contain water only, as the partitions keep out the ice. These water spaces are convenient as affording opportunities for quickly emptying a pitcher into water if it becomes necessary. In one corner of each trough is placed a pipe, through which the water may be drawn off into the escape E, when the operation is finished.

The pitchers stand on narrow wooden strips, which raise them off the bottom about two inches, thus giving the cold water free access all about them, and when in position are well under the overhanging hoods, C_1, C_2. These hoods are flat wooden boxes, wide at the bottoms and drawn in at the tops, where they fit against openings in the chimney, D, D. In the lower part of the chimney, on the floor below, is placed a grate and fire door (not shown in figure).

Each pitcher receives eighteen to twenty pounds of the acid mixture (according to the strength of the latter). All are then set in place in the troughs, covered with glass plates, surrounded with ice and water, and allowed to stand until completely cooled. Into each bottle is put two pounds of glycerine.

When the acid in the pitchers has fallen to the temperature of the surrounding ice water, the covers are removed from the pitchers, and the air-tubes passed through holes in the hoods down into them. Through these air-tubes a strong current of air is forced by means of a pump driven by steam. This current of air keeps the contents of the pitchers in continual agitation. The air for the pump is drawn through sulphuric acid to render it perfectly dry, and just before it enters the air-main over the troughs it is thoroughly cooled.* The cool-

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* The pump draws its air from the top of a large tight box; in the bottom of the box is placed a leaden pan containing sulphuric acid (oil of vitriol), in which is immersed a flat spiral of lead pipe. The inner end of the pipe is closed, and the outer end rises out of the acid and passes through the side of the box into the open air. A great number of small holes are bored in the spiral. As fast as the air is drawn from the upper part of the box the outside air enters through the pipe, bubbling up through the acid. Drying the air is not absolutely necessary; but it is better to do it, as it can be so readily accomplished. Cooling does not entirely remove moisture, and the quantity of air forced through the pitchers is large.

ing arrangement is made of ten coils of small tin pipe, which are surrounded by ice (or better, ice and salt).* These coils are so arranged as to give an extensive cooling surface without impeding the current.

As soon as the air-current has been turned on, the flow of glycerine is begun. Each rubber tube c is a siphon, which is started by suction through a glass tube inserted in the outer end. As soon as the glycerine runs freely, the suction tube is withdrawn, and a fine-pointed glass jet put in its place. The glycerine runs from this jet in a fine stream directly into the pitcher under it. In cold weather, the glycerine may become too thick to flow easily. To overcome this, the bottles of glycerine are warmed by passing steam through the pipe behind them until the glycerine is sufficiently thin.

The glycerine dropping into the acid mixture is rapidly acted on and converted into nitro-glycerine. The reaction may be indicated by the equation —

$$C_3 H_8 O_3 \; + \; 3 \, H \, N \, O_3 \; = \; C_3 \, H_5 \, N_3 \, O_9 \; + \; 3 \, H_2 \, O.$$
Glycerine.   Nitric Acid.   Nitro-glycerine.   Water.
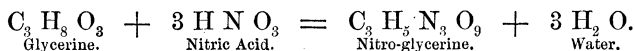
The reaction is accompanied by a considerable evolution of heat. This heat must be removed; for, if the temperature be allowed to rise too high, the glycerine is not converted into nitro-glycerine, but is oxidized or burned, with formation of other substances. The limits of temperature are very narrow. Starting at 32°, the temperature must not be allowed to exceed 48°, and at 50°–55° there is great danger of "firing" taking place. The liquid in the pitchers is kept cold by surrounding them with ice-cold water and by the stream of cold air passing into the acid. The most important work of the air-current is to keep the acid mixture in constant agitation. In this way, the heat generated is quickly diffused through the whole, preventing any sudden local rise of temperature.

The glycerine is much lighter than the acid mixture, and would be apt to collect in little pools above it; and when these were broken up, and a quantity of glycerine suddenly brought

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* This is much preferable to allowing the air to come into direct contact with the ice.

into contact with the acid, the action would be so rapid that it could not be controlled.

While the glycerine is running into the pitchers, observations with the thermometer are constantly made of the temperature attained in them. If in a pitcher the temperature is found to be rising too rapidly and to be approaching the higher limit, the glycerine is evidently running in too fast, and its flow must be checked, which is done by pressing down the conical wooden plug in the stopper of the glycerine bottle. This plug passes through the same opening as the rubber glycerine tube; therefore, when it is pressed down, it compresses the latter so that less liquid can pass through. If the temperature is too high or continues to rise, the plug is forced hard down, closing the glycerine tube altogether. The flow of glycerine being checked or stopped, the pitcher rapidly cools down again. As soon as the thermometer shows this to be the case, the plug is loosened and the flow again set up. Constant care is therefore necessary, but the operation is a simple one, easily learned and performed by ordinary workmen.

If the limit of temperature is exceeded, "firing" takes place, indicated by the copious evolution of red, nitrous fumes, and in extreme cases by flame. Usually when this action occurs, it is easily controlled by stopping the glycerine stream and stirring vigorously the contents of the pitcher, but if it is violent, the pitcher must be emptied into water as quickly as possible.

During the operation of conversion, acid and irritating fumes are given off in large quantities, greatly to the injury of those compelled to breathe them. In the apparatus used at the Station, these are entirely removed through the hoods and chimney. A fire in the grate at the bottom of the chimney causes a powerful draught in the hoods, which overhang the pitchers, drawing upwards all the fumes and discharging them into the open air. Generally a small fire at first is sufficient, and often no fire is necessary.

This arrangement for removing the fumes has proved to be of great advantage, not only to the health of the workmen,

but also to the operation itself, since they can attend more thoroughly to their work without inconvenience. The hexagonal shape of the apparatus is of course not important, but happened to be convenient for the building in which it is placed and the number of pitchers to be used. In larger establishments, the same principle can easily be applied in other ways.

Separation and Washing of the Nitro-glycerine.

As soon as all the glycerine has been run into the pitchers the conversion is complete, but the nitro-glycerine has to be separated from the large quantity of acid still remaining. This acid is almost entirely sulphuric acid, very nearly all the nitric acid having been used up in the reaction.

The nitro-glycerine is partly in solution and partly suspended in the heavy acid liquid. On diluting the acid with water, the portion in solution is precipitated, and, as nitro-glycerine is a much heavier liquid than the diluted acid, the whole of it settles to the bottom.

A sketch illustrating the separating and washing apparatus is given on Plate II. The large wooden tub A is sunk in the floor of the converting room. It is filled about three-fourths with water, and has a cover with a square opening, in which is placed a leaden strainer. By means of a rubber hose connected with an air-pipe, a current of air is led to the bottom of the tub, vigorously agitating the water in it. The pitchers are taken from the converting apparatus, and their contents poured through the strainer into the tub. The acid liquid descends in fine streams, and is quickly diffused through the whole body of water.

When all the pitchers have been emptied, the air-pipe is withdrawn, and a short time allowed for settling. The heavy nitro-glycerine collects at the bottom of the tub, so that the lighter acid water may be drawn off from above it. A wooden stop-cock, b_1, is put into the side of the tub, a short distance from the bottom, but above the level of the nitro-glycerine. Through this, the supernatant acid liquid is run off and led by a rubber hose into the drain g. The tub is placed in an

inclined position, and in the lowest part of the bottom is another wooden stop-cock b_2. Through this the nitro-glycerine is drawn in small quantities into the washing-tub B.

The washing-tub is of wood, lined with lead, and is supported by trunnions in the wooden frame E. The trunnions are placed just above the middle, so that the tub will stand upright and yet can be easily turned or inverted.

Directly over the washing-tub are the pipes d and e, provided with valves within the reach of the workman standing by the tub. One is a water-pipe, and there is attached to it a short piece of hose. The other is connected with the air-main, and has a piece of hose long enough to reach to the bottom of the washing-tub.

A portion of the nitro-glycerine in the large tub A having been drawn into the tub B, the air-hose is put in and a stream of water turned on. The air-current causes a strong ebullition, raising and spreading the nitro-glycerine through the water. As soon as the tub is full, the water is turned off and the air-hose removed. The nitro-glycerine rapidly settles to the bottom of the tub, so that in a few minutes the water above it may be poured off by turning the tub on its trunnions.

This operation is repeated until the nitro-glycerine is thoroughly washed, when it is poured into a copper pail, and a new portion taken from the large tub.*

When the wash-water is decanted from B, it falls first into the tub C. As soon as this tub fills, the water runs off through the large lead pipe f, which descends nearly to the bottom of c, into the tight, open drain g. In this tub any nitro-glycerine which may have floated or been accidentally poured off has an opportunity to settle, and is saved.

The building in which nitro-glycerine is made at the Station is situated close to the shore, and the tight drain, g, extends below high-water mark.

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* Very thorough washing can be obtained by this method. Nitro-glycerine is a heavy oily liquid, so that any ordinary washing fails to remove the acid contained in it. The powerful stream of air, however, breaks up the heavy oil into small globules, which are thrown up into the water above, so that there is a good opportunity for the washing action.

When all the nitro-glycerine has been sufficiently washed, it is poured into earthen jars, and allowed to stand, covered with water, until it " clears," when it is ready for use.*

The time required for making a run of nitro-glycerine is about five hours, not including the time required for cooling the pitchers, which will, of course, be different at different seasons. The quantity made in this apparatus, when all the pitchers (24) are in use, is about eighty pounds.

(For other methods of making nitro-glycerine, see " La Dynamite et la Nitro-glycerine," Champion ; " Jahresbericht der Chemischen Technologie," Wagner, 1868 ; " Polytech-nisches Journal," Dingler, vols. 187 and 206 ; " Handbuch der Chemischen Technologie," Bolley, 1874 ; Report of Se-lect Committee on Explosive Substances, House of Commons, June 26, 1874, Evidence concerning Works of British Dyna-mite Company.)

Composition and Properties.

Nitro-glycerine is composed of carbon, hydrogen, nitrogen, and oxygen. According to the equation on page 25, its formula is $C_3 H_5 N_3 O_9$. This is the formula for trinitrin (tri-nitro-glycerine). There are three nitrins or nitro-glyce-rines, which may be formed by the action of nitric acid on glycerine. These are mononitrin, $C_3 H_7 (NO_2) O_3$; dinitrin, $C_3 H_6 (NO_2)_2 O_3$; and trinitrin, $C_3 H_5 (NO_2)_3 O_3$.

According to the equation, trinitrin is the only one formed, but it is very probable that the conversion into trinitrin is not *perfect* under any circumstances, dinitrin (and possibly, mononitrin) being produced to a small extent. It is also very probable that oftentimes, owing to use of weak nitric acid or to careless operating, the lower nitrins are almost entirely obtained.

Gun-cotton, or trinitro-cellulose, is formed by a strictly analogous reaction which has been carefully studied ; and it is found that the conversion is not *perfectly* accomplished, although at the present time the necessary conditions are so well understood that a nearly complete conversion can be

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* See page 23.

produced. It is also known that the low pyroxylines are more easily decomposed than the highest; and there is no doubt that some of the earlier accidents with gun-cotton were due to the ready decomposition of the imperfectly converted material.

The nitrins may be similarly constituted. The different properties assigned by various writers to nitro-glycerine can be accounted for only on the supposition of differences in composition of the substances experimented with. Probably the nitro-glycerines operated with were mixtures of the nitrins in various proportions. If the conditions of the formation of the different nitrins are worked out, many anomalies in the behavior of nitro-glycerine will disappear.

Theoretically, according to the equation on page 25, 1 part of glycerine should give 2.46 parts of nitro-glycerine. In practice we get 1.6 to 1.75 parts. This difference is due partly to losses in operating, and partly to the fact that the glycerine used is not anhydrous. Also, nitro-glycerine is not the only product of the reaction. In three experiments on a small scale, made by the writer at the Station, using pure anhydrous glycerine and the strongest possible nitric acid, the results obtained were 1.96, 1.89, and 2.03 parts of nitro-glycerine to one of glycerine used. This departure from the theoretical proportion is due in large part to the formation of bodies soluble in water, which are removed in washing.

Champion and Pellet * state that 100 grms. of chemically pure glycerine yielded 190 grms. of pure nitro-glycerine.

At ordinary temperatures nitro-glycerine is an oily liquid, having a specific gravity of 1.6.† Freshly made, it is creamy-white and opaque, but becomes transparent (" clears ") and colorless, or nearly so, on standing for a sufficient time depending on the temperature.

What change takes place during this " clearing " is not yet understood. It is, however, of considerable importance to the manufacturer, as by observing it he can arrive at the purity (freedom from acid) of his nitro-glycerine. At moderately

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* Bulletin Soc. Chim. XIX. 494.

† Some writers give a lower specific gravity.

low temperatures, if the nitro-glycerine does not contain free acid, the " clearing " goes on slowly, requiring from one to two weeks for its accomplishment. At 60°–70° it goes on rapidly, two or three days being a sufficiently long time. Free acid hastens the operation greatly. During clearing, the acid retained by the nitro-glycerine seems to be separated, and its presence may be observed in the water above. If the nitro-glycerine has been properly made and well washed, no acid or only traces of acid should appear. If a slight amount of acid should be found, it may be readily removed by changing the water frequently for several days, or by washing the nitro-glycerine a few times, by pouring it into fresh water through a fine strainer. After this, if an acid reaction again shows itself, the material is impure, and decomposition must be going on. Such nitro-glycerine should be used as quickly as possible, and while it is kept, must be carefully looked after and frequently washed.

Nitro-glycerine does not mix with, and is unaffected by, water. It has a sweet, pungent, aromatic taste, and produces a violent headache if placed upon the tongue, or even if allowed to touch the skin at any point. Those constantly using it soon lose their susceptibility to this action.

Freshly made, opaque nitro-glycerine does not freeze until the temperature is lowered to 3°–5° below 0° Fah., but the transparent or cleared nitro-glycerine freezes at 39°–40° Fah. Nitro-glycerine freezes to a white crystalline mass. When frozen, it can be thawed by placing the vessel containing it in water at a temperature not over 100° Fah.

Pure nitro-glycerine does not spontaneously decompose at any ordinary temperature ; but, if it contains free acid, decomposition is apt to occur. It is, therefore, very important that all acid should be removed by thorough washing when it is made. A number of samples of nitro-glycerine are now in the magazine of the Torpedo Station, which have been kept from two to four years without special precautions, and which are entirely unaltered. No instance has yet been noticed of the spontaneous decomposition of properly made and purified nitro-glycerine. This is a matter of the greatest importance.

In connection with the explosion at San Francisco, April 16, 1860, it was said that fumes had been noticed coming from the box containing the " blasting oil," which shortly after exploded with terrible violence. Other similar cases have been noted. There can be no doubt that many accidents, said to be due to " spontaneous decomposition," were really owing to the bad quality of the material. The presence of free acid in nitro-glycerine (as in gun-cotton) tends to produce decomposition with the formation of acid products and the evolution of heat. These accelerate the decomposition, which, therefore, rapidly increases. If the amount of nitro-glycerine is small and it is freely exposed, it may decompose entirely into gases which disappear, so that no residue will be left; but if there is a large quantity of it, or it is confined, so that the gases formed cannot freely escape, its temperature will rise until the ignition point (which, of course, is much lower for the decomposing and highly sensitive nitro-glycerine than for the pure substance) is reached, and explosion takes place. Doubtless this has occurred again and again, and the natural consequence of ignorance and neglect is called " a mysterious explosion," " an inscrutable event," etc. *Nitro-glycerine requires intelligent handling.* Many accidents have occurred with it; but it must be deemed wonderful that they have been so few in number, when it is considered that this highly explosive material is largely made and handled by men ignorant of its constitution and true properties. Surely, the use of so powerful an explosive is sufficiently hazardous at the best, without increasing its dangers.

Manufacturing nitro-glycerine cannot be a mere rule-of-thumb operation, if the product is to be of good quality and reasonably safe. The conduct of the process of conversion is simple enough; but the operator must know that his glycerine is pure, that his acids are of the right strength, that the conversion is completely performed, that the washing is thorough, etc. With such knowledge, he will be able to economize his materials while producing the largest amount of product of the best quality.

Nitro-glycerine in a state of decomposition becomes very

sensitive to blows, exploding violently when struck, even when unconfined.

Pure nitro-glycerine is not sensitive to friction or moderate percussion. If placed upon an anvil and struck with a hammer, only the particle receiving the blow explodes, scattering the remainder.

It must be noted that if completely confined the effect may be different, since from its liquid form it is nearly incompressible. In the above case local explosion only occurs, because the hammer is lifted, and the rest of the nitro-glycerine is blown away. But if it was so confined that there was no escape for the effect of the explosion of the particle first struck, the whole mass would probably be fired.

If flame is applied to freely exposed nitro-glycerine, it burns slowly without explosion. The firing-point is about 180° C. (356° F.) It begins to decompose at a somewhat lower temperature.

Mode of Firing.

Nitro-glycerine is usually fired by means of a fuse containing fulminating mercury. By such a fuse it is detonated, producing a very violent explosion. Fired with a fuse charged with gunpowder, its action is very uncertain; sometimes it is exploded, and sometimes it is not; but, when so exploded, its explosive force is much less than when the fulminate is used.*

When frozen, nitro-glycerine cannot be fired, even by large charges of fulminate.†

Storing and Transportation.

Nitro-glycerine may be conveniently kept in large earthen jars, with a layer of water over the explosive. If it is to be transported, the liquid form is very inconvenient, especially from the danger of leakage. It is, therefore, advisable to

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* A great many experiments have been made at the Station with gunpowder fuses, but no satisfactory or concordant results have been obtained.

† In one instance 1,600 pounds of the liquid exploded in a magazine which contained, also, 600 pounds of the frozen. The latter was broken up and scattered in every direction without being exploded.

freeze it and carry it in the frozen state, when it is perfectly safe. For transportation, it should be put in strong tin cans holding about forty-five or fifty pounds. Each can should be paraffined on the inside and have, passing vertically through its centre, a tin tube, so that freezing or thawing may be more easily accomplished.

All vessels in which nitro-glycerine has been kept should be destroyed when not wanted for the same use, as the nitro-glycerine cannot be easily washed off.

Use and Relative Force.

Nitro-glycerine is the most powerful explosive in use. In difficult blasting, where very violent effects are required, it surpasses all others. In spite of the many accidents that have occurred with it, it has been found to be so valuable that its use has steadily and largely increased.

Its liquid form is a disadvantage, except under favorable circumstances, as when made at the place where it is to be employed. It, however, forms the essential ingredient in a number of solid mixtures, which will be taken up farther on. When used in blasting or similar work, it is usually put in tin cans or cartridge cases.

Since nitro-glycerine is so readily detonated, it has the advantage of not requiring strong confinement. Even when freely exposed it will exert violent effects, such as breaking masses of rock or blocks of iron. So, in blasting, it requires but little tamping. Loose sand or water is entirely sufficient.

The relative force of nitro-glycerine is not easily estimated, since the effect produced depends greatly on the circumstances. Thus, a charge of nitro-glycerine in wet sand or any soft material will exercise but a slight effect, while the same charge will shatter many tons of the hardest rock. In the former case much more sand would be thrown out by a slower explosion, which would gradually move it, than by the sudden violent shock of the nitro-glycerine, which would only compress the material immediately about it. But in the hard rock, the sudden explosion is much more effective than the same amount of force more slowly applied. Roughly, it may

be said that nitro-glycerine is eight times as powerful as gun-powder, weight for weight.

Products of Decomposition.

On explosion, nitro-glycerine is resolved entirely into the gases, — carbonic anhydride, water, nitrogen, and oxygen, the last-named appearing only in small quantity. If explosion is imperfectly accomplished, oxides of nitrogen are formed, and the total quantity of gas is lessened. If fully exploded, no disagreeable or poisonous gases are given off.

NITRO-GLYCERINE PREPARATIONS.

The explosive preparations containing nitro-glycerine will be taken up in this place, since they are but forms in which nitro-glycerine itself is presented for use. Their explosive power is derived from the nitro-glycerine in them; so that they are not explosive mixtures in the sense in which that term has been employed in these pages.

In all of them nitro-glycerine is present as nitro-glycerine, but it is mixed with some absorbent substance or vehicle. In this way a solid or semi-solid substance is obtained, which is much more convenient and safer to use than the liquid itself.

DYNAMITE.

In dynamite, the absorbent is usually a natural silicious earth. Deposits of this silicious earth are found in many places, notably in Hanover. From the Hanover earth, the original dynamite was made. This silicious earth, or "kiesel-guhr," is a fine white powder, composed of the skeletons of microscopic animals (infusoria). It has a high absorptive power, being capable of taking up from two to three times its weight of nitro-glycerine without becoming pasty.

Artificially prepared silica has been proposed by the writer as a substitute for the natural earth, and has been used at this Station with good results. This silica is prepared by precipitating it from a solution of sodium silicate (water-glass) by sulphuric acid, washing and drying. Its absorbent

power is a little less than that of the natural earth, but it retains the nitro-glycerine very well.

The process of making dynamite is very simple. The nitro-glycerine is mixed with the dry, fine powder in a leaden vessel with wooden spatulas.

Dynamite has a brown color, and resembles in appearance moist brown sugar. It usually contains from sixty to seventy-five per cent of nitro-glycerine. In this country, dynamite is made and sold under the name of giant powder.

The explosive properties of dynamite are those of the nitro-glycerine contained in it, as the absorbent is an inert body. It freezes at the same temperature as its nitro-glycerine to a white mass. If solidly frozen, it cannot be fired; but, if loose and pulverulent, it can be exploded, although with diminished violence. It can be thawed by placing the vessel containing it in hot water.

The keeping qualities of dynamite are those of the nitro-glycerine it is made from. It is safer because it avoids the liquid condition, and from its softness it will bear blows much better. Exudation must be guarded against. Therefore, it must not contain too much nitro-glycerine, especially if it is liable to be exposed to comparatively high temperatures, which tend to make the nitro-glycerine more fluid, and consequently less easily retained.

The firing-point of dynamite is the same as its nitro-glycerine. If flame is applied to it, it takes fire and burns with a strong flame, leaving a residue of silica. It is not sensitive to friction or moderate percussion.

Mode of Firing.

Dynamite is fired by a fulminate fuse. Gunpowder will fire it, but not with certainty, and the effect obtained is much less than when the stronger agent is employed.

Use and Relative Force.

Dynamite is the best of the nitro-glycerine preparations, and is indeed the best form in which nitro-glycerine can be used. It has earned a good reputation for safety, in spite of

the horror usually excited by nitro-glycerine, or any thing connected with it. It contains more of the explosive agent than the other nitro-glycerine preparations, and is therefore stronger. Safer than the liquid nitro-glycerine, from its mechanical condition, it is not complicated by the admixture of substances which may exercise injurious effects.

It is used for blasting and other purposes instead of nitro-glycerine. It is now extensively employed in mining and quarrying with excellent results, and its use is constantly increasing. Much more effective than powder, it is practically safer, since it is not liable to explosion by sparks or flames. Carelessness is therefore less likely to be followed by accident. For military purposes also, it is largely employed.

The explosive force of dynamite is, of course, that of the nitro-glycerine contained in it. If it contains seventy-five per cent, its comparative force may then be approximately stated at six times that of gunpowder, weight for weight.

<center>DYNAMITE NO. 2.</center>

Dynamite proper contains only nitro-glycerine and the silicious absorbent. Mixtures containing other substances are sometimes included under the same name. The true dynamite is often called " Dynamite No. 1," and the others " Dynamite No. 2," or receive fanciful names. All these mixtures contain less nitro-glycerine than the No. 1, so that they cost less per pound, but of course they are proportionately less powerful. Possibly they may sometimes be of use.

The following are varieties of No. 2 dynamite made in England.*

	Per cent.		Per cent.
Nitrate of Soda	69.00	Nitrate of Potash	71.00
Paraffine	7.00	Paraffine	1.00
Charcoal or Coal Dust	4.00	Charcoal	10.00
Nitro-glycerine	20.00	Nitro-glycerine	18.00
	100.00		100.00

* Report of Select Committee of House of Commons on explosive substances, 26th June, 1874.

It is hard to see any advantage in these mixtures except that they are cheaper, and might be applied to uses where the great violence of the larger amount of nitro-glycerine is not needed, and yet a sharper explosive than powder is wanted. It is improbable that any useful effect is obtained from any other ingredient than the nitro-glycerine. Those containing deliquescent salts (nitrate of soda, for example) are objectionable from their liability to exudation. All of them will be injured by water, which dissolves the salts, which are the principal ingredients.

It is easy to see that the number of such mixtures that might be made is very great, for almost any dry salt or powder may be taken as an absorbent.* No special value would attach to any of them. The only requisites would be that the absorbents should not exert any injurious action, and that no more nitro-glycerine should be present than could be perfectly retained at the highest temperature that would probably be experienced.

Many of these mixtures have been proposed and made, but it is undesirable at the present time to touch upon more than a few of the most prominent, which will serve as examples.

LITHOFRACTEUR.

Lithofracteur is a mixture which has the composition (Trauzl) —

	Per cent.
Nitro-glycerine	52.00
Kieselguhr	30.00
Coal	12.00
Soda Saltpetre	4.00
Sulphur	2.00
	100.00

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* During the siege of Paris, in 1870, nitro-glycerine and dynamite were made in the city in considerable quantity for military purposes. The glycerine was obtained from the candle factories, but of course the silicious earth was unattainable. Many experiments were made to discover a good absorbent. Pulverized brick, tripoli, charcoal, magnesia, chalk, lampblack, and others were rejected as not possessing sufficient absorptive powers. Finally, the ash of the coal used for gas-making was hit upon This was a white powder, mainly composed of aluminum silicate, and capable of taking up twice its weight of nitro-glycerine, without becoming plastic. The mixture so made was called dynamite.

Sometimes, instead of the sodium nitrate, the potassium or barium salt is used, and variations made in the quantity of nitro-glycerine present. Like all the nitro-glycerine preparations, lithofracteur has no necessarily definite composition, being merely a mixture made according to the caprice of the manufacturers.*

This preparation is made by Krebs Bros. & Co., in Cologne, and has been used to some extent in Europe. It is claimed by the makers that the other substances (coal, saltpetre, and sulphur) mixed with the nitro-glycerine increase the quantity of gas delivered, and, therefore, the explosive force. This is not, however, correct. Nitro-glycerine is so sudden in its explosion that nothing can be added to it from the slower burning of any of the other combustible ingredients, which are present in comparatively small amount, and in bad proportions. Neither does the presence of these substances add any thing to the safety of the mixture. They tend to lower its firing-point, and render it more easily exploded.

Lithofracteur must be regarded as inferior to dynamite proper, especially for military purposes. It is much more liable to exudation.

The mixtures known in this country as giant powder No. 2, rendrock, etc., and those already spoken of under the head of dynamite No. 2, are similar to lithofracteur; but in them the silicious earth is generally omitted.

DUALIN.

Dualin is a mixture made by Carl Dittmar, a Prussian, of nitro-glycerine, sawdust, and saltpetre, in about the proportions —

	Per cent.
Nitro-glycerine .	50.00
Fine Sawdust .	30.00
Saltpetre .	20.00
	100.00 (Trauzl.)

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* Experiments with lithofracteur in England by Special Committee, &c. Experiments in 1872 with a lithofracteur containing 66.7 per cent of nitro-glycerine showed great liability to exudation. In 1873 the manufacturers submitted another sample of 47.5 per cent, which, of course, retained the nitro-glycerine much better.
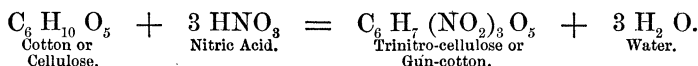
This preparation is also inferior to dynamite. The saw-dust and saltpetre have much less absorptive power than the silicious earth, and retain the nitro-glycerine comparatively feebly. Its firing point is said to be considerably lower than that of dynamite. Also, its lower specific gravity is a draw-back.

CHAPTER III.

GUN-COTTON.

Composition and Formation.

GUN-COTTON has the composition indicated by the formula $C_6 H_7 (NO_2)_3 O_5$, or $C_6 H_7 N_3 O_{11}$, and is formed by the action of concentrated nitric acid on cotton. The reaction consists in the substitution of nitrogen and oxygen in feeble combination for part of the hydrogen in the cotton or cellulose, and is, therefore, similar to the one by which nitro-glycerine is produced. The equation illustrating the reaction may be thus written : —

$$C_6 H_{10} O_5 \ + \ 3\,HNO_3 \ = \ C_6 H_7 (NO_2)_3 O_5 \ + \ 3\,H_2 O.$$

Cotton or Cellulose.   Nitric Acid.   Trinitro-cellulose or Gun-cotton.   Water.

A number of these substitution products are known, but only one is used as an explosive agent. Some of the others are largely employed for making collodion.

Cotton is the purest form of cellulose, but the latter is the principal part of the ligneous fibre of plants, so that similar products may be obtained from other vegetable fibres.

The process of making gun-cotton consists essentially in exposing the dry cotton for a sufficiently long time to the action of a mixture of the strongest nitric acid with sulphuric acid, and in thoroughly washing the gun-cotton thus prepared to remove the excess of acid. In this reaction also, the duty of the sulphuric acid is to take up the water, which is a secondary product.

The fibres of cotton are long, flattened tubes, often twisted and knotted. To ensure complete conversion, therefore, considerable time must be allowed for the acid to fully penetrate, and very great pains is necessary to wash out the remaining acid. Thorough washing is, however, difficult. If any acid

is left in the gun-cotton, spontaneous decomposition may ensue, resulting in explosion.

Gun-cotton has been known for a long time, and many attempts have been made to manufacture and use it, but until recently without success. Accidents, which could only be referred to spontaneous decomposition, cast doubts upon its safety and permanency. The trouble lay in the imperfect purification of the gun-cotton. By the method of Abel, a very perfect washing is obtained, and in addition, the material is prepared in a form convenient to use, and yet perfectly safe.

The essential features of Abel's process are the reduction of the wet gun-cotton to a fine pulp, which can be easily washed, and the compression of this pulp into convenient shapes. This product evidently cannot be used for certain purposes for which the fibre is required, such as in gunnery. This is not of importance, as gun-cotton is no longer so applied. For other applications, such as blasting, demolitions, torpedoes, etc., the pulped and compressed gun-cotton is an admirable agent, and is the only form of this explosive now used to any extent.

The following method of preparing long-stapled gun-cotton has, however, been employed at the Torpedo Station with very good results on the small scale : —

PROCESS OF MAKING LONG-STAPLED GUN-COTTON.

Good raw cotton or carded cotton is used. In either case it is treated with a weak solution of sodium carbonate, which removes a small quantity of resin from the raw cotton, or oil from the carded. The purified cotton is washed and carefully dried. The acids are the strongest nitric acid, specially prepared for this purpose, and sulphuric acid (oil of vitriol). They are mixed in the proportions of three parts by weight of sulphuric acid to one of nitric.

A considerable quantity of the acid mixture is placed in a leaden pan, and a little dry cotton immersed in it. When thoroughly saturated, the cotton is lifted by an iron fork and placed upon a perforated iron shelf, which hangs in the pan.

As much as possible of the acid is removed from it by pressing. It is then placed in an earthen jar. A quantity of fresh acid, sufficient to replace that removed in the cotton, is then added to the dipping pan and a new portion of cotton put in. When the earthen jar is half full of the dipped cotton, fresh acid is poured into it until the cotton is covered, and it is set away in a cool place for forty-eight hours. The greater part of the conversion takes place during the dipping, but in order that it should be complete, it is necessary that the cotton should remain in contact with strong acid for a long time.

The gun-cotton is then taken from the jars and passed between a pair of rolls (covered with rubber, or better, lead), held together by springs, which are supported in a frame over a trough. Almost all the excess of acid is thus removed.

The gun-cotton is next thrown in a tub of water and vigorously stirred about.

It remains to remove all traces of acid by washing. This is done by passing the gun-cotton through a clothes-wringer a number of times. The clothes-wringer is so mounted that the water pressed out is led away, and the squeezed gun-cotton falls into fresh water.* In this way, a more thorough purification is obtained in a short time than by the ordinary method of very long exposure to the action of running water.

ABEL'S PROCESS FOR MANUFACTURING PULPED AND COMPRESSED GUN-COTTON.†

Materials. Cotton waste is the form of cotton used. It is picked and cleaned, thoroughly dried at 160° Fah., and allowed to cool.

The acids are the strongest nitric and sulphuric acids, mixed in the proportion of one part of the former to three of the latter by weight. They are mixed in large quantities, and stored in cast-iron receiving tanks.

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* The use of a clothes-wringer for this purpose was suggested to the writer by Mr. Charles H. Wing, now Professor of Chemistry in the Institute of Technology, Boston, Mass., by whom it had been employed.

† Naval Mission to Europe; Captain Edward Simpson, U. S. N. ; Factory at Waltham Abbey, England.

Treatment with Acid. Cotton in one-pound charges is immersed in the acid mixture, which is contained in a trough surrounded with cold water. After a short exposure to the action of the acid, the cotton is taken up, placed upon a perforated shelf, and as much as possible of the acid squeezed out from it. It is then put into jars, covered with fresh acid, and the jars placed in cold water, where they remain for twenty-four hours.

Removal of Acid. The gun-cotton from the jars is thrown into a centrifugal strainer, which expels from it nearly all of the acid. It is then diffused quickly in small quantities through a large volume of water, and again passed through a centrifugal machine.

Pulping and Washing. Thorough washing is necessary to remove the traces of acid still adhering to the gun-cotton. The washing is expedited and rendered complete by the operation of pulping. The pulping is performed in pulping engines or *beaters.* A *beater* is an oblong tub in which is placed a revolving wheel carrying strips of steel on its circumference. From the bottom, under the wheel, project similar steel strips. By the rotation of the wheel, the gun-cotton suspended in water circulates around the tub, and is drawn between the two sets of steel projections, which reduce it to a pulp. The bottom is movable, so that the space through which the gun-cotton must pass may be contracted as the operation goes on.

When the pulping is complete, the contents are run into the *poachers* for the final washing. A *poacher* is a large, oblong wooden tub. At the middle of one side is placed a wooden paddle-wheel, which extends half way across the tub. In the poacher, the pulp is stirred for a long time with a large quantity of water. The revolution of the wheel keeps up a constant circulation, and care is taken that no deposit occurs in any part of the tub.

Preparation of the Gun-cotton Pulp for Use.

In the previous operations, the cotton has been converted into gun-cotton, and the gun-cotton reduced to a pulp and

thoroughly washed. The pulp is next to be separated from the large volume of water in which it is suspended, and compressed into cakes or discs. This is accomplished in two presses. The first press has thirty-six hollow cylinders, in which perforated plungers work upwards. The plungers having been drawn down, the cylinders are filled with the mixture of pulp and water, and their tops covered with a weight. The plungers are then forced up by hydraulic power. The pulp is compressed, the water escaping through the perforations in the plungers.

In the second press, the cylindrical masses of gun-cotton from the first press are more highly compressed, a pressure of six tons to the inch being applied.

About six per cent of water remains in the cakes, which can be removed by drying.

Properties and Modes of Firing.

The conversion of cotton into gun-cotton causes very little change in its appearance. The latter is somewhat harsher to the touch than the former.

Gun-cotton is insoluble in, and unaffected by, water. If flame is applied to dry, loose gun-cotton, it flashes up without explosion. Dry, compressed gun-cotton burns rapidly but quietly when ignited by a flame. Moist, compressed gun-cotton under the same circumstances burns away slowly.

Even if a considerable quantity of gun-cotton is inflamed, it will burn away without explosion; but, if the quantity is too great, the explosion of a part will be produced. In such cases the outer portion confines the inner sufficiently to cause its explosion.

Dry, unconfined gun-cotton can be violently exploded by a small amount of fulminating mercury. Even in the compressed, wet state, gun-cotton can be exploded; but to accomplish this it is necessary to apply the shock from the explosion of a small amount of the dry.

For firing wet, compressed gun-cotton, a "primer" is used, which is a cake of the dry, to which is attached a fulminate fuse. This primer must be enclosed in a water-proof bag or box.

The firing-point of gun-cotton is about 360° Fah. (182° C.). Gun-cotton is not sensitive to friction or percussion. Imperfectly converted or badly washed gun-cotton is liable to spontaneous decomposition, which may result in explosion if the conditions are favorable. The pulped and compressed form is free from such danger, for since it can be fired wet there is no need of ever drying it, so it may be kept and used saturated with water.

Wet, compressed gun-cotton is the safest of all explosive agents. It is not liable to be fired by a spark or a flame, nor affected by blows, friction, or other rough handling. It has not been made in this country, but has been largely manufactured in England. The English government uses large quantities of it in torpedoes, and for other military purposes. Its use was rapidly extending in England, when it received a sharp check by the explosion at the Stowmarket factory, August 11, 1871. On investigation, it was shown that sulphuric acid in considerable amounts had been added to a quantity of finished gun-cotton, and the conclusion was arrived at that this had been *wilfully done* by some unknown persons. It is impossible that compressed gun-cotton, which had passed through the processes of manufacture, could have remaining in it any material quantity of acid, yet some gun-cotton, which had been sent from the factory just before the accident occurred, was found to have in it a great deal of acid, and to be in a state of active decomposition. This would tend to show that this accident was not due to any inherent defect in the gun-cotton, and consequently, confidence has been largely restored to this explosive.

Storage, Handling, and Transportation.

Compressed gun-cotton is stored in the wet state. Care must be taken that it is not exposed to a temperature that will freeze the water in the cakes. If this occurs, they are liable to be disintegrated by the expansion of the water in freezing. In cold climates, it is therefore advisable to store gun-cotton in pits below the reach of frost, about six feet from the surface.

For convenience in handling, gun-cotton is made into discs of various dimensions, or it may be pressed into slabs or blocks, which may be sawn, drilled, or cut as desired.

The transportation of gun-cotton presents no special difficulties, since there is no danger of leakage, neither is it sensitive to blows. In England, many of the railroads transport it as readily as other freight.

Use and Relative Force.

As already stated, the use of gun-cotton in gunnery has been given up. The compressed gun-cotton is not adapted to such use, but the violence of its explosion when fired by a detonator makes it of value in torpedoes, and for engineering purposes. For these uses it is largely employed in England. Professor Abel also proposes to use it in shells, and some recent experiments seem to indicate that this may be done to advantage.* A very small charge will break up a shell much more completely than a much larger amount of powder. Experiments were tried with 16-pounder shells, filled with water and fused with an ordinary percussion fuse, to which was attached a small cylinder containing half an ounce to one ounce of dry, compressed gun-cotton, and the fulminate necessary to detonate it. This arrangement was very successful, the shell breaking up well.

It was concluded : — " That shells filled with water, and containing a small bursting charge of dry gun-cotton, could be safely fired from field guns ; that with one-ounce or half-ounce bursters of gun-cotton and detonators containing fifteen grains of fulminate of mercury the 16-pounder common shell filled with water would burst far more effectually than under ordinary circumstances when filled with powder."

Experiments were also tried with 9-inch shell filled with lumps of wet gun-cotton to the amount of ten or twelve pounds. A dry gun-cotton detonator was used, as in the 16-pounder shell. This charge burst a shell into an enormous number of pieces.

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* Committee on Explosives, War Department, England.

Very good results were also obtained in practice against targets representing troops.

The relative force of gun-cotton as compared with gun-powder is variously given from 4–6 to 1. The latter figure is probably nearly right, for gun-cotton which is fully exploded.

Products of Decomposition.

On explosion, gun-cotton is almost entirely converted into gases, only a trifling residue being left. The gases formed are carbonic acid, carbonic oxide, water (converted into steam by the heat of the reaction), nitrogen, and a small amount of marsh gas (Karolyi).

The combustion is not so complete as when nitro-glycerine is fired. The latter contains more than oxygen enough to oxidize all its carbon and hydrogen to carbonic acid and water, while the quantity in gun-cotton is insufficient to do this, and a considerable proportion of carbonic oxide is formed. This does not much affect the volume of gas formed, but the heat evolved is considerably less than if the oxidation of the carbon was more complete.

GUN-COTTON PREPARATIONS.

Nitrated Gun-cotton. This is made by soaking the compressed gun-cotton in a saturated solution of saltpetre (potassium nitrate), and drying.

Chlorated Gun-cotton. This is similarly made, using potassium chlorate instead of nitrate.

Some advantage might be gained by mixing with gun-cotton substances that would furnish oxygen, since as already stated, it does not contain enough for complete oxidation. The two preparations mentioned might therefore be serviceable. But since it has been discovered that wet gun-cotton can be exploded, this form is used in preference to all others.

CHAPTER IV.

PICRATES AND FULMINATES.

THE PICRATES.

General Composition and Properties.

THE picrates are salts of picric acid. Picric or trinitrophenic acid is a nitro-substitution product, formed by the action of nitric acid on carbolic acid (phenol, $C_6 H_6 O$). Three substitution products may be derived from this action, but only one, picric acid, possesses any marked explosive properties.

Picric acid has the composition indicated by its symbol, — $C_6 H_3 (NO_2)_3 O$, or $C_6 H_3 N_3 O_7$. Picric acid is found in commerce, being used to dye silk and wool yellow. If the acid is heated, it takes fire and burns sharply and rapidly, without explosion. The picrates are all exploded with more or less violence by heat or blows. When used as explosive agents, they are mixed with potassium nitrate (saltpetre) or potassium chlorate.

A large number of picrates are known, but the potassium and ammonium salts are the only ones that have been much used in explosive preparations.

Potassium Picrate. $C_6 H_2 K N_3 O_7$.

Most violently explosive of the picrates. Potassium picrate and potassium chlorate form a mixture nearly as powerful as nitro-glycerine, but it is so sensitive to friction or percussion as to render it practically useless. With potassium nitrate instead of chlorate, a less violent mixture is obtained, but one still too liable to accidental explosion. Designolle's powder is a mixture of potassium nitrate (saltpetre) and potassium picrate. His blasting powder was composed only of these two ingredients, but his musket and cannon powders contained

charcoal also. Considerable quantities of this powder were made and experimented with in France, but its use was given up after the occurrence of a severe accident in Paris.

Ammonium Picrate. $C_6 H_2 (NH_4) N_3 O_7$.

This salt has been proposed by Abel as an ingredient of a powder for bursting charges of shells. The properties of ammonium picrate are very different from those of the potassium salt. If flame is applied to the former, it burns quietly, with a strong, smoky flame. If heated, it melts, sublimes, and burns without explosion. It is almost entirely unaffected by blows or friction. This salt, mixed with saltpetre, forms Abel's picric powder. Experiments with this powder in England indicate that it possesses some advantages when used in shells.* A number of shells charged with it were fired from guns of different calibre without accidents. It is more powerful than gunpowder, and less violent than nitro-glycerine and gun-cotton. It is insensitive to ordinary means of ignition. If flame is applied to it, the particles touched burn, but the combustion does not readily extend to the others. Blows or friction do not explode it. It must be confined in order to develop its explosive force. It does not absorb moisture from the air, so that it may be stored and handled like gunpowder, and is at least equally safe and permanent. It is prepared for use by the usual gunpowder processes of incorporation, — pressing, granulation, &c.; so that it has the same form, and may be handled in the same way.

Brugere† has also proposed a mixture of ammonium picrate and saltpetre as a substitute for gunpowder, and claims that it is less hygroscopic than ordinary powder, more powerful and more uniform in its effects.

Such a mixture may therefore be of use when a more violent explosive than gunpowder is wanted, and neither gun-cotton nor nitro-glycerine is available.

A powder containing ammonium picrate is being experi-

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* Investigations and Applications of Explosive Agents. F. A. Abel.
† Comptes Rendus, 1869, 716.

mented with at the Torpedo Station, with a view to using it in spar and other torpedoes.

The picrate is prepared from picric acid and ammonia. The picric acid is dissolved in water, and ammonia added to neutralization. Another charge of picric acid is then dissolved in the same liquid, and ammonia again added. This is repeated several times, and the liquid allowed to stand for some time, when the ammonium picrate crystallizes out in large quantities. The mother liquor is drawn off, the crystalline deposit drained and dried. The mother liquor may be used for the preparation of successive lots of the ammonium salt until it becomes charged with impurities, when it may be otherwise treated or thrown away. In this way a considerable amount of the salt can be expeditiously prepared with little labor and without much loss. The simple mixture of saltpetre and ammonium picrate would not furnish a powder sufficiently coherent to bear the handling that it would receive, if applied to the uses for which it is intended. Therefore, in making the mixture, to be carried through the usual gunpowder processes, a small quantity of charcoal has been added to give the required cohesiveness. In this way has been prepared a powder of good grain, which is less hygroscopic than gunpowder. Its other properties remain to be shown.

THE FULMINATES.

The fulminates are salts of fulminic acid ($C_2 H_2 N_2 O_2$). The mercury salt is the only one of practical value. All of them are easily exploded, and some are excessively sensitive. Their explosions are very sharp from the extreme rapidity of their decomposition, but, from the small amount of gas given off, the force exercised is not very great. The explosive effect obtained is of a local character.

Composition and Formation.

Fulminating mercury has the composition indicated by the symbol $C_2 Hg N_2 O_2$. It is formed by the action of mercuric

nitrate and nitric acid upon alcohol. The best mode of preparing it is as follows : —

Dissolve 1 part of mercury in 12 parts of nitric acid, sp. gr. 1.3, and pour this solution into 11 parts of alcohol, 85 per cent.* Place the vessel containing the mixture in hot water until it darkens and becomes turbid, and begins to evolve dense white fumes. It is then removed from the water. The reaction goes on, with strong effervescence and copious evolution of dense white ethereal vapors. If red fumes appear, cold alcohol should be added to check the violence of the action. The operation should be performed at a distance from a fire or flame, and in a strong draught, so that the vapors will be carried away. When the liquid clears and the dense white fumes are no longer given off, further action is stopped by filling up with cold water.

The fulminate settles to the bottom of the vessel as a gray crystalline precipitate. The supernatant liquid is then poured off, and the fulminate washed several times by decantation or upon a filter.

Properties and Uses.

Dry fulminating mercury explodes violently when forcibly struck, when heated to 186° C. (367° Fah.), when touched with strong sulphuric acid or nitric acid, by sparks from flint and steel or the electric spark.

When wet it is inexplosive. It is therefore always kept wet, and dried in small amounts when wanted for use.

Its explosive force is not much greater than that of gunpowder, but it is much more sudden in its action.

The readiness with which it may be fired makes it an excellent means of causing the explosion of other substances, and it is for this purpose only that it is used. It finds many

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* A number of methods are given by various authors, but this is the best. Theoretically, 1 part of mercury should yield 1.42 parts of fulminate, but in practice a less amount is produced. By the above method, the writer has obtained 1.18 and 1.24 to 1, a better result than by any of the others. Some of the mercury passes off in the vapors, and a little remains in the liquid. With these proportions, there is little tendency to decomposition of the fulminate, with re-formation of metallic mercury.

applications — either pure or mixed with other bodies — in percussion powder, percussion caps, primers, fuses, detonators, &c. It presents many advantages for this use. It is of special importance for the peculiar power it possesses of causing the violent explosions called detonations. (See page 13.) It is, therefore, a requisite for exploding nitro-glycerine, gun-cotton, and their preparations.

Detonators or detonating fuses are charged with pure fulminating mercury, — 15 to 25 grains in each. Fifteen grains is a sufficient charge for nitro-glycerine or its preparations; one of twenty-five grains is used with compressed gun-cotton. In detonating fuses, the fulminate should be contained in a copper cap or case, and must not be loose. Charging should be done with wet fulminate, as it is very dangerous to handle it when dry.

Properly made fulminate fuses or exploders are perfectly safe, but unless care is taken in making them they may be dangerous.

CHAPTER V.

CLASSES OF EXPLOSIVE MIXTURES.

GENERAL COMPOSITION.

As has been already remarked, an explosive mixture has two essential ingredients. One is a substance which is readily combustible, and the other, one containing a large amount of oxygen, which it will easily give up. The combustible substance in almost all cases is carbon, with which is usually associated hydrogen. Occasionally other oxidizable bodies, such as sulphur, are also used, but carbon is the most important element. It is largely employed in the form of charcoal, which is nearly pure carbon, but evidently any organic substance containing it in large proportion will serve nearly as well. In all cases the action is the same. The carbon is oxidized to carbonic acid gas and the hydrogen to water, with great evolution of heat. The number of combustible substances that may be used in this way is very great, but all of them play the same part in the mixtures.

The substance in an explosive mixture which is to supply the oxygen must be one containing that element in large amount, in such a condition that it can easily be released, and one which will not act directly on the other substance or substances present.

The nitrates and chlorates are powerful oxidizing agents, and are almost invariably used in explosive mixtures. There is a great difference in the readiness with which these two kinds of salts give up their oxygen, and, consequently, they form different classes of explosive mixtures. We may, therefore, divide the usual explosive mixtures into two divisions,—

1st, Those containing nitrates, and
2d, Those containing chlorates.

1st, *The Nitrate Class.*

In the nitrates, the oxygen is held with considerable force, so that a strong external influence is required to separate it. In general then, the mixtures made from the nitrates are not very easily exploded, and their action is, comparatively speaking, moderate. Compared with those of the second class, they are not sensitive to friction or percussion. Any of the nitrates may be used in explosive mixtures, but, practically, potassium nitrate (saltpetre) is the only one employed to any extent. With sulphur and charcoal, it makes up the numerous compositions, of which gunpowder is the most important. Occasionally sodium nitrate (Chili saltpetre) is used instead of the potassium salt, but its tendency to deliquesce makes it much inferior. Gunpowder may be considered as the representative of the nitrate class, and its well-known explosive properties may be taken as those of all mixtures belonging to the class.

Picric powder (already described) belongs to this class. Sawdust powder, or Schultze's white gunpowder, contains saltpetre. It is made by converting purified sawdust into a nitro-cellulose (resembling gun-cotton), and mixing this with the nitrate. It is said to work well in small arms.

2d, *The Chlorate Class.*

Chlorate mixtures are very sensitive to friction and percussion, and they explode with great sharpness.

The potassium salt is the only one of the chlorates which is employed in these mixtures. Very many chlorate mixtures have been made, but none of them are of much value. Of many of them it may be said that they are so liable to accidental explosion that they are unfit for use.

The following are examples of chlorate mixtures : —

Potassium chlorate with rosin.
    ,,   ,,   ,,   galls (Horsley's powder).
    ,,   ,,   ,,   gambier (Oriental powder).
    ,,   ,,   ,,   sugar (used in " chemical " fuses).
    ,,   ,,   ,,   potassium ferrocyanide (white or German gunpowder).
    ,,   ,,   ,,   tannin (Erhardt's powder).
    ,,   ,,   ,,   sulphur (Pertuiset powder, used in explosive bullets).

Potassium chlorate is the basis of many fuse mixtures and primings, some of which are used to a certain extent.

SPRENGEL'S NITRIC ACID AND POTASSIUM CHLORATE MIXTURES.

Sprengel has published some interesting and important statements in regard to certain new classes of explosive mixtures.* He finds that a variety of organic substances dissolved in nitric acid of 1.5 sp. gr. explode by detonation. Nitro-benzol, with nitric acid in proper proportion, gives a mixture which explodes with intense violence, if fired by a detonating fuse. Absorbed in silicious earth, this mixture gives a preparation which burns slowly when flame is applied, and is less sensitive to blows than dynamite or gun-cotton. Picric acid dissolves in nitric acid, forming a similar mixture. Many other combustibles may be thus used, but these mixtures are inconvenient to handle, since they contain concentrated nitric acid. Still their power and cheapness are so great that they may be of value. He points out a new mode of preparing potassium chlorate mixtures, which avoids the dangers and difficulties usually connected with them. Mixing potassium chlorate with solid combustible substances is an extremely dangerous operation, and the mixtures so made are very sensitive. He uses instead combustible *liquids*, absorbing them in porous cakes or lumps of potassium chlorate, which can be done without risk. These mixtures are not exploded by fulminate, unless a certain amount of sulphur or nitro-compound is present. For example, carbon disulphide and nitro-benzine give mixtures that in blasting granite proved to be four times as effective as gunpowder. But, by increasing the power of the detonator, a mixture of the chlorate with a hydrocarbon (benzine, petroleum, phenol) could be satisfactorily fired. This was done by surrounding the detonator with an envelope of gun-cotton. These results are of great importance. They indicate methods of making explosive agents that will compare very favorably with those now in use, in cheapness, power, and safety. The readiness

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* Journal of Chem. Soc., Vol. XI. 796.

and simplicity with which they may be prepared makes it possible to keep the ingredients separate until the mixture is required for use. This has been previously attempted, but is impracticable when two solids are used, but much easier with two liquids or a solid and a liquid.

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CHAPTER VI.

USE OF NITRO-GLYCERINE AND GUN-COTTON.

GENERAL REMARKS.

EXPLOSIVE agents are largely used in mining, quarrying, submarine blasting, and in many engineering operations. Gunpowder is the oldest of them, and still is the one most extensively employed. Very many substitutes for it have been proposed, but nearly all have failed to achieve practical success. But the demand for a more powerful blasting agent has become pressing, and other bodies have begun to supplement, and to a considerable extent, to replace gunpowder. Not only is a violent explosive of great value in ordinary mining and blasting work, but there are difficult engineering operations undertaken at the present time, which could hardly be performed if powder was the only destructive agent that could be applied. Careful study and dearly-bought experience have greatly increased our knowledge of the characteristics and peculiar properties of the violent explosives, so that it is possible to use them with a great degree of safety.

We find, therefore, that in every direction their use is rapidly extending. It is not at all probable that gunpowder will ever be entirely displaced by them as a blasting material. No other explosive agent possesses its peculiar properties, or can be used instead of it under all circumstances. But for certain purposes, explosives of greater power are very useful, and for these purposes they will replace powder. To a large extent, however, their use will be additional to that of powder, since they can be advantageously applied where the latter is comparatively ineffective.

Of the numberless explosive preparations that have been brought forward, we need only consider, for practical purposes, nitro-glycerine and gun-cotton. These two are the only violent explosive agents that have been brought into

actual and extensive use, and they promise to be still more largely employed in the future.

Nitro-glycerine is used in the liquid state, and is the essential ingredient in several solid or semi-solid mixtures. Of these mixtures, dynamite is the best, and it may be taken as a representative of the class to which it belongs. In these remarks, the term nitro-glycerine will be used as a general expression, including all the forms in which that body is used, since it is the essential substance in them all.

Gun-cotton has been used in the dry state, but, since the discovery that it can be exploded when saturated with water, the wet form is almost the only one used.

Comparison as Blasting Agents.

In the preceding pages, liquid nitro-glycerine has been said to be eight times as powerful as powder, dynamite (75 per cent nitro-glycerine) as six times, and gun-cotton as 4–6. These figures are merely rough approximations to the relative force exerted by the bodies in question. They furnish but a poor means of comparison for practical purposes, as the circumstances of use exert an important influence on the result obtained. Thus we find in practice, that, in certain kinds of blasting, a violent explosive (*e.g.*, dynamite or gun-cotton) will do much more than six times as much work as powder, with less expense for drilling, etc. Again, under other conditions, there will be but a slight difference in the actual effect produced. Therefore no exact comparison can be made which does not include the circumstances of use.

Mr. Nursey * gives figures showing the amount of material removed or thrown down to the pound of powder, under various circumstances of practice : — 85,232 lbs. of chalk ; 31,860 lbs. of hard, white sand ; 22,000 lbs. of lime-stone (8,900 lbs. by small charges) ; 32,430 lbs. of basalt ; 14,280 lbs. of hard conglomerate. Taking these figures, and considering nitro-glycerine eight times as powerful as powder, it is not

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* Explosive Compounds for Engineering Purposes. Society of Engineers, 1869.

likely that the former would move eight times as much sand or chalk as the latter, although it would throw down much more than that proportionate quantity of hard, firm rock.

In general, the harder and firmer the material to be blasted, the more effective proportionally nitro-glycerine or gun-cotton will be. In soft material, the reverse is true. In hard rock, the single violent shock of the detonating explosive has an irresistible shattering effect which is widely extended, while the slowly gathered force of powder is resisted much better. But in soft material, the sharp blow merely moves or compresses the particles in the immediate neighborhood of the explosion, while the slower, accelerating force of the powder will be transmitted, and will displace large masses. Under favorable conditions therefore, the relative force of the violent explosive agents will considerably exceed the figures given above, while under others it may fall below them.

A violent explosive is indicated wherever great destructive action is desired, as in rock-cuttings, tunnelling, removing obstructions under water, etc. There is no advantage to be gained by its use, in moving soft stuff, or where it is desired to avoid finely breaking up the material, as in most quarrying, coal-getting, etc.

In blasting, the smaller amount of drilling required when a violent explosive is used is a great advantage. Also in many cases the shattered condition of the rock thrown out is of considerable importance.

Comparing together nitro-glycerine and gun-cotton, it may be said that liquid nitro-glycerine is the more powerful, producing from one-fourth to one-half more effect according to circumstances. Dynamite (75 per cent nitro-glycerine) and gun-cotton are usually placed very near together. The lower grades of dynamite, and other mixtures containing small amounts of nitro-glycerine, of course fall below gun-cotton. As a rule, the mixtures poor in nitro-glycerine are not economical to use, although their cost is considerably less than that of the richer ones. As already remarked, the available force they possess is that of the nitro-glycerine they

contain, and it is evident that the less this is diluted with inert substances the more effectively it can be applied. It often happens, however, that more work seems to be done proportionally with such a poor mixture than with a richer one or with the liquid itself. This is either because the full effectiveness of the high explosive has not been developed, or because the great force it exerts has not been fully utilized. If the stronger explosive is properly handled, its superiority will be demonstrated. The absurdity of the claim of greater power often made for a preparation poor in nitro-glycerine over a richer one is evident, unless it can be proved that a part is greater than the whole. Further, it is hardly worth while to buy any more silica, saltpetre, saw-dust, or charcoal than is absolutely necessary, when nitro-glycerine is the body required. They can be purchased at a much lower price than is charged for the explosive preparation.

In regard to comparative safety in use, both nitro-glycerine and gun-cotton are preferable to powder, since they are not so liable to accidental explosions caused by the carelessness of those handling them. A large proportion of the accidents with explosives are caused by the extreme carelessness or recklessness of those using or handling them.* Powder is constantly used with neglect of ordinary precautions, and the natural consequence is, that accidents frequently occur. The fact that nitro-glycerine and gun-cotton are not exploded by sparks or by flame, greatly diminishes the chances of accident from careless handling.

Nitro-glycerine in the liquid state cannot be as safely handled by ordinary workmen as when in the condition of dynamite or similar solid preparation. Liquid nitro-glycerine can be safely handled by an intelligent, careful person, who thoroughly understands its properties, but its liquid condition is an inconvenience, making it hard to transport and handle, liable to be spilled and to be lost from leakage, etc. Also the incompressibility of the liquid renders it more likely

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* Compare Parliamentary Report on Law relating to Gunpowder and other Explosives, Major Majendie, R. A., 1874; Accidental Explosions, F. A. Abel, Royal Institution, March 12, 1875.

to be affected by certain kinds of shocks or blows than the soft, pulverulent dynamite. Dynamite is, therefore, on the score of safety, much better than liquid nitro-glycerine for general use as a blasting agent. It should be borne in mind, however, that it is better only on account of its mechanical condition. The nitro-glycerine in it is the same body chemically that it was before it was mixed with the absorbent. The necessities of purity and careful preparation apply to all forms of nitro-glycerine.

The greatest danger connected with the use of dynamite and other preparations containing nitro-glycerine is the exudation of the liquid explosive. To avoid this, no more nitro-glycerine must be present than the absorbent is capable of retaining at all temperatures.* It is desirable also, that none of the absorbent ingredients should be deliquescent or acted upon by water; for, if the preparation should be wetted, liquid nitro-glycerine would separate. In these respects, dynamite is better than the other mixtures that have been spoken of. Its silicious earth has a very high absorptive power, and is not affected by water. Saline mixtures are objectionable on both these points.

Gun-cotton in the wet, compressed state may be considered as perfectly safe to handle. Properly made, there is no danger of spontaneous decomposition at any natural temperature, and its wet condition insures its freedom from accidental explosion. Dry, compressed gun-cotton is highly inflammable, although it is not exploded by flame, if unconfined.

Gun-cotton, as now made, has not been used in this country, although in England it finds extensive application.†

Using and Handling.

Liquid Nitro-glycerine. Liquid nitro-glycerine is used to

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* Nitro-glycerine at 50°–60° Fah. is a thick liquid, which is easily retained, but at 90°–100° Fah. it becomes quite limpid, so that separation will occur unless there is a sufficient excess of absorbent to hold it.

† In 1874, the Bureau of Ordnance, Navy Department, imported five hundred pounds for experiments at the Torpedo Station.

a considerable extent in blasting, although its solid prepa-
rations (dynamite, etc.) are rapidly replacing it. It is
the most effective of all explosive agents, but inconvenient
to transport and keep. In blasting, it may be poured directly
into the drill-holes, if they are tight, but there is always dan-
ger that some of it may find its way into crevices in the rock
and not be exploded, — remaining to cause accident at another
time. Usually it is put into tin cases.

The writer uses a cartridge-case, made by rolling up stout
brown paper on a wooden former into a cylinder of the
desired diameter, glueing it, and fastening into one end a
cork by choking with fine wire ; when dry, dip the case in
melted paraffine. The fuse-wires should pass through a
cork, which fits the open end. This cork may be firmly
fastened in the case by means of small tacks. Cases thus
made are impervious to nitro-glycerine, and are much cheaper
and better than tin ones.

In handling liquid nitro-glycerine, care must be taken to
avoid spilling it. Cartridge-cases, when they are to be filled,
should be placed in a shallow box or trough containing dry
earth or sand, which will absorb any liquid accidentally
spilled. Copper vessels should be used for carrying and
handling liquid nitro-glycerine. These should be prepared
for use by first brushing them over with boiled linseed oil,
and then thinly coating them with melted paraffine.

In thawing frozen nitro-glycerine, the vessels containing it
are placed in water at 100° Fah. Water at the same temper-
ature may also be poured on the top of the frozen mass, and
frequently changed. The desired temperature may be con-
veniently attained by bringing the water to the point at
which its heat can just be borne by the wrist.

When it can be used, water is a convenient and satisfac-
tory tamping. Instead of water, moist sand or earth is often
used. Hard tamping is of course unnecessary.

Dynamite. Dynamite may be placed directly in the bore-
holes, as there is no danger of leakage, but it is generally
used in the shape of paper-covered rolls or cartridges.
When frozen, it is thawed by placing the vessel containing

it (in bulk or made up into cartridges) in water not over 100° Fah.

In using it in blasting, it is not safe to use force to drive down a cartridge which has become jammed in the hole. Several fatal accidents have been caused by doing this.

Dynamite is very little affected by water, unless broken up and scattered by it. If the charge is kept together, mere contact with water is without effect. Many of the other nitro-glycerine preparations are readily penetrated and injured by water, so that they will not bear much exposure to it. Water-tamping can therefore be used with dynamite only. Generally sand or earth is employed.

Gun-cotton. Gun-cotton is manufactured for rock blasting in discs of various sizes, from seven-eighths of an inch to two inches in diameter, and from one to two inches thick. Larger discs of from three to seven inches diameter are prepared for making up large charges, as in breaking up wrecks or removing obstructions under water. In rock work, the discs may be placed directly in the bore-holes one above another, or they may be rolled up in a few turns of thin, strong paper to form cartridges. In other cases, the gun-cotton may be put in any suitable bag or box.

Generally the wet gun-cotton is the best form to use. Of course there is no need of protecting this from water, so that wet tamping may be employed with it.

When it is desired to use dry gun-cotton, the operation of drying may be readily performed in a steam drying-oven. When dry gun-cotton is wanted, the nitrated form is to be preferred.

Dry gun-cotton must be carefully protected from water, since, if it becomes wet, the detonating cap or exploder ordinarily used with it will fail to fire it.

Drilling. It is evidently of the greatest importance, in mining or quarrying with nitro-glycerine and gun-cotton, that the drill-holes should be round and of uniform size. Since, in nearly all cases, the explosive agent is used in the shape of cartridges (gun-cotton having itself the cylindrical form), great trouble will be occasioned if the holes are not well

drilled. If the holes are irregular, only a cartridge or disc small enough to pass clear can be used, so that the loss of space and charge may be serious.

Storage and Transportation.

Liquid Nitro-glycerine. Liquid nitro-glycerine may be conveniently kept in earthenware jars or crocks, placed in troughs containing dry, fine earth ; each jar should not be more than two-thirds full of the explosive, and the remaining space should be occupied by water. The water over the nitro-glycerine should be changed occasionally, perhaps two or three times a month, or oftener if necessary. When the water is changed, it should be examined to see if it is acid. If the nitro-glycerine has been properly made and thoroughly washed, no trace of acidity will be developed.

In cold weather, nitro-glycerine freezes, and requires no attention, except to thaw it when needed for use. In warm weather, it may be kept in the same condition by artificial means, and consequently perfectly safe. This can only be done, however, at considerable trouble and expense, which are not really necessary if the material is reasonably pure.

For transportation, liquid nitro-glycerine may be conveniently put in strong tin cans, holding about fifty pounds each. These cans should be paraffined on the inside by treatment first with boiled linseed oil, and then with melted paraffine. Nitro-glycerine can be best transported in the frozen state, when it is entirely free from danger, and all chance of leakage is avoided. Freezing of the liquid may be easily accomplished by placing the cases containing it in ice-water for a few hours. When it is once solidly frozen, thawing takes place slowly, so that, if the cans are packed in ice and carefully covered, they may be carried long distances without difficulty.

Dynamite. Dynamite may be conveniently kept in tight boxes or other suitable vessels. If exudation is found to be occurring, the dynamite should be thoroughly re-mixed, and if necessary, a small amount of absorbent added to it. Cartridges should not be placed together in large numbers, or

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piled upon one another. If they are to remain in store for some time, or to be transported to considerable distances, they should be packed as snugly as possible without jamming, in shallow boxes of moderate size, so that they will stand on end. The better way is to make up the cartridges at the place where they are to be used.

The transportation of dynamite does not seem to be attended with any special difficulty, if ordinary care is taken.

Gun-cotton. Gun-cotton in the wet state seems to be perfectly safe, and it should always be stored and transported in that condition. Even when it is to be used dry, it should be dried only as it is wanted for use. It should be placed in wooden boxes holding about fifty pounds each, and kept in a damp or not very dry locality. Evaporation, however, does not go on very rapidly, so that the quantity of water lost from this cause is not very great, even under unfavorable circumstances. An occasional sprinkling of the floor of the store-house or magazine will almost entirely prevent evaporation.

The transportation of wet, compressed gun-cotton is free from all danger and difficulty.

Modes of Firing.

As has been previously stated, detonating fuses or exploders * must be used to explode nitro-glycerine and gun-cotton. Such exploders should contain fulminating mercury. Attempts have been made to use, with nitro-glycerine, exploders charged with gunpowder. Liquid nitro-glycerine can be more readily fired by powder than its solid preparations, but in all cases the explosion is imperfect as well as uncertain. Other substances have been employed in ex-

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* The terms fuse and exploder are here used with the same meaning. Fuse is a word which has the disadvantage of being applied to many very different arrangements for causing ignition of explosive charges. Exploder is sometimes applied to the electric apparatus used in firing (for instance, Wheatstone's exploder), but in this country, among blasters, the word exploder is applied to the electric fuse or the detonating cap, and fuse is restricted to the ordinary or running fuse.

ploders with partial success. Fulminating mercury is, in every respect, the best agent for producing detonation.

Liquid nitro-glycerine can be certainly fired by a smaller amount of fulminate than the soft, solid preparations. A charge of 15–20 grains of fulminate is large enough for use with any form of nitro-glycerine.

Electrical fuses or exploders are generally used with the violent explosives in this country, and it is hardly necessary to point out the advantages gained by their use. The principal objection that can be brought against them, is that they are in many cases of an extremely sensitive and dangerous character. The instances of accidental explosions that can be traced to the use of dangerous electrical exploders are very numerous. There is no need of this, for electrical exploders can be made to be perfectly safe. In most cases, the defect in the construction of such exploders is the use of very sensitive priming substances. This is done in order to obtain certainty of explosion under all circumstances, or to cover inferior materials and workmanship. Exploders containing such over-sensitive priming are very liable to accidental explosion in handling, or even by atmospheric electricity. The latter cause has frequently produced accident. Great numbers of exploders for use with frictional electric machines have been made so sensitive to induced currents, that electrical disturbance of the air has often fired them. Such exploders are not only very dangerous, but are also often irregular and uncertain, in spite of their sensitiveness.

If really good and safe electrical exploders are to be made, care and expense must be put into their preparation. Contractors, mine-operators, and others employing violent explosives, often lose severely by their own mistaken economy or carelessness in using inferior electrical exploders. The cost of exploders is but a very small item when compared with the cost of the blasting material, and the expenses attending its use. A single accident, that would not have occurred if good exploders had been used, will often cost the operator much more than all the exploders he uses in a year.

It would be beyond the intended scope of this work to

enter into a discussion of the different kinds of electric exploders and electric apparatus used in blasting. It is proper to remark, however, in regard to electrical exploders, that they must be very accurately made if certainty of firing is to be obtained with them. By electrical means, simultaneous firing of a number of charges can be brought about, which is of great value. But when a number of exploders are to be fired together, it is evident that unless they are very correctly made, miss-fires will be apt to occur. Great trouble is often caused by the use of irregular or uncertain exploders.

Too much care cannot be exercised by those using explosive agents, in getting good exploders. It has been clearly demonstrated that the mode of firing explosives is one of the most important points connected with their use. If it is neglected, satisfactory results cannot be expected.

Instead of electric exploders, the ordinary running fuse (Bickford or Toy fuse) is sometimes used in firing nitroglycerine and gun-cotton. The running fuse alone will not explode them, so that a detonator is also employed. This is a copper cap charged with fulminate, which is fixed to the end of the running fuse. The junction of the cap and fuse must be carefully protected when used in liquid nitro-glycerine, in order to prevent the soaking of the fulminate. The fuse itself must be impervious to water or nitro-glycerine, if it is to come in contact with the explosive. With dynamite or similar preparations, care must be taken that sparks from the burning fuse do not get to the explosive lest it should be set on fire and burn away entirely or partially, without explosion. It is better to use gutta-percha-covered fuse, and the cap should not be buried too deeply in the charge.

The most convenient way of joining the fuse and cap is to pass the fuse through a small tapering bit of wood, which fits into the cap nicely. The fuse can be firmly glued into the wood, and the junction made tight with gutta-percha, or in any other convenient manner, before putting the wooden plug into the cap. The joint between the cap and the wooden plug can be made tight enough for immediate use by smearing with hard soap or paraffine.

In all cases, the detonator or cap must be in contact with the explosive agent.

Dry, compressed gun-cotton like nitro-glycerine, is fired by fulminating mercury, either in an electric exploder or in a cap attached to a piece of running fuse. A larger charge of fulminate is necessary with gun-cotton than with nitro-glycerine, not less than twenty-five grains.

When running fuse is used, there is danger of setting the gun-cotton on fire by sparks from the fuse; and as it burns very rapidly, it might be consumed without explosion taking place. To avoid this, use strongly covered fuse, and sink the cap no deeper in the disc than is necessary to insure the full action of the fulminate. Electric exploders, if good ones, are, of course, infinitely preferable to running fuse and caps.

The most important point is to obtain actual contact between the exploder or detonating cap and the gun-cotton. The former must be firmly attached to the disc of gun-cotton, otherwise only scattering or inflammation may take place.

Wet, compressed gun-cotton requires a peculiar exploder, or " primer " as it is called, to fire it. This primer is a small charge of dry, compressed gun-cotton, detonated by fulminating mercury. For blasting in drill-holes, the primer is a disc of dry gun-cotton of the same size as those making up the charge, and to this disc is attached an electric exploder or a cap and fuse. The primer is placed on top of the other discs. The primer, of course, must not be allowed to become wet. If the holes are dry, it will be sufficient to separate it from the wet discs by a piece of water-proof paper, but generally, it is necessary to protect the primer by coating it with a varnish or with paper rendered impervious to moisture. The primer for large charges (100–500 pounds) contains from one-half pound to two pounds of dry gun-cotton. It must be carefully enclosed in a water-tight bag or box.

Relation between Charge and Effect.

It is very desirable in blasting to properly proportion the charge to the work it has to do. If the charge is too small,